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SURFACE CHARACTERISTICS OF USED HIP PROSTHESES

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16. Abstract

McKee-Farrar total hip prostheses removed from patients after relatively short service were subjected to critical examination for surface characteristics. Evidence suggested that the wear process was initiated by adhesion and subsequently progressed to abrasive wear. Wear tended to be concentrated in isolated areas, suggesting localized load bearing areas and lack of conformability of the femoral ball and the acetabular socket. Measurement of unworn areas indicated the initial geometric variations to be greater than would be expected in precision bearing fabrication.

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SUMMARY

Although the use of total hip prostheses has been rather limited, many encouraging successes have been achieved. There is concern among orthopedic surgeons, however, as to the possible effects of wear debris on adjacent tissue and with regard to having the useful life limited by wear. To minimize those concerns, it is important to understand the wear processes that occur as a basis for seeking minimized wear. Prosthetic devices removed from patients after short (e.g., 1 yr) periods of use were studied to clarify the wear problems. Micrography and profile measuring techniques were utilized. Wear was initiated by adhesive processes and progressed by abrasion phenomena. The geometry of the prostheses showed well-defined wear patterns.

INTRODUCTION

Metals have been used to repair and replace human bones and joints since the 18th century (ref. 1); however, that usage is still inadequately understood. Among the problems with metal components are method of fixations, compatibility with bone and tissue, and wear of parts in sliding contact. Where metal components must slide against one another as in a metal artificial human hip joint ball and socket, lubrication and wear considerations are important. Lack of lubrication data may account for the fact that the full prosthesis has only recently been widely used by orthopedic surgeons. Indications for such surgery have included advanced age and as a consequence very limited long duration experiences are available as background. A number of full hip prostheses have been removed, however, after 1 or 2 years of service for varied reasons including sepsis and loose fixations. Several of those prostheses were made available for examination.

The objective here is to report on examinations of several used total prostheses. Those studies utilized advanced measurement devices capable of critical determination of geometry of surfaces. Macro and micro variations in surface geometry were determined and that information was complemented by microscopic examinations. The studies were intended to suggest possible mechanisms of wear important to prosthetic joints and to indicate possible areas for further research to achieve improved lubrication as well as minimal friction and wear.

Inspection Equipment

The surface texture and roundness gage ("Talysurf and Indiron") equipment used to examine the prostheses were electromechanical devices with measurement accuracies of the order of a millionth of an inch (10^{-5} mm). A metallurgical microscope was also used.

Roundness gage. - The roundness gage was used to measure the roundness of the ball and socket at the equator and latitudes as shown in figure 1. A schematic of the roundness gage with a prosthesis mounted in place for examination is shown in figure 2. The gage consists of an ultra-precision spindle and turntable with a radial runout of not more than 0.0000005 inch (0.000013 mm). The prostheses were mounted on the spindle turntable by the cylindrical fixture. A displacement transducer supported from a stationary arm has a 0.032 inch (0.813 mm) diameter ball stylus which slides against the surface to be measured. The spindle table is rotated by a variable speed motor. The displacement transducer electrical readout is with a polar chart recorder that records an amplified radius. The polar chart is mechanically driven from the spindle turntable at a 1 to 1 ratio.

Surface texture gage. - The surface texture gage measures the true profile of a surface. A schematic of the device for measuring surface texture of round components is shown in figure 3. In this device the component to be measured is mounted on a stationary table. The pickup transducer is mounted on a spindle which rotates through 200° arc around the specimen to be measured. Radial runout of the spindle is not greater than 0.000005 inch (0.00013 mm). The transducer pickup has a 0.0001-inch radius (0.00254-mm) diamond stylus which slides against the component to be measured with a force of about 100 milligrams. The spindle supporting the pickup transducer is rotated by a variable speed drive motor. The pickup transducer is recorded on a linear fixed chart speed recorder. The output chart trace is curvalinear (i.e., the deviation from a straight line is the deviation from a true circle).

A standard metallurgical microscope was used to examine scratches and texture to complement the mechanical geometrical measuring equipment.

Inspection Results

The complex motions and loads that occur in a hip joint hint that careful consideration should be given to the load distribution at the ball and socket. Visual inspection (without optics) of the prostheses showed that to be a problem area. The contact between the ball and socket was approximately 50 percent of the total area and the major portion of contact was between the equator and 45° latitude. This amounts to approximately 50 percent of the projected area to carry the load.

Further clarification was made with the roundness gage. Measurements were made with this equipment at -15°, equator, 30°, 45°, and 60° latitude on the ball and equator, 30°, 45°, and 60° latitude on the socket. Out of roundness results are shown in table I. The average measurements for two prostheses varied from 0.00012 inch (0.00458 mm) to 0.0007 inch (0.00805 mm). For comparison, ball bearings are manufactured with roundness accuracies of 0.000005 inch (0.00013 mm). Figure 4 is a isometric view of typical polar chart roundness data with amplified radius that emphasizes geometric variations from both manufacture and wear.

Deep scratches were observed on both the ball and socket. The predominant scratches on the ball appeared to extend from 30° to 45° latitude and were linear. Similar scratches have been generally observed on prostheses that have been removed from patients. Orthopedic investigators can identify by the location and direction of scratches the side of the patient from which the prosthesis was removed. Abraded scratches in the socket were circular in direction near the pole.

Figure 5 are surface profile traces of a used metal hip joint prosthetic ball. Figure 5(a) shows two scratches on a hip joint ball of the type illustrated photographically in figure 6. The profile (fig. 5) indicates a low spot on the curvature. Greater magnification in figures 5(b) and (c) illustrates more clearly the characteristics of two scratches shown in figure 5(a). The presence of metal above the normal surface level suggest that plastic deformation and surface welding have accompanied the abrasive wear process.

Although corrosive wear can be a problem and is discussed later, there was no direct evidence of such wear with the chrome-cobalt (Vitallium alloy) metal used.

DISCUSSION OF WEAR MECHANISM

The conditions imposed on the human hip joints are discussed in reference 1, and the relevant fundamental concepts on boundary film lubrication are described in reference 2. Adsorbed films (liquids and gas) separate loaded surfaces and will shear if relative motion takes place. Such films can adequately protect surfaces against failure under lightly loaded conditions. However, as the loading of the surface is increased or greater stresses of other types are imposed, the adsorbed films are very likely penetrated. In that case, a reaction film (such as the metal oxides normally present on metals or deposited solid films or reaction products of the lubricant with the films) can prevent contact between the nascent materials. Ultimately, if the protective films break down, clean surfaces come into contact and surface welding will occur. Welds formed in this manner are also characteristic of friction, wear, and adhesion experiments performed in vacuum where surfaces are clean. The welds are often stronger than either of the base metals, by virtue of alloying at the interface or of work hardening. If there is subsequent relative motion by the surfaces, the welded junction must fragment or shear at some point. If the junction is indeed stronger than either base metal, shear will occur in the base metal substrate and a solid hard particle is left adhering to one of the surfaces. That particle may subsequently break loose from either surface and be an isolated wear particle. The formation and shear of welded junctions is the basic tenet of the adhesion concept or mechanism of friction and wear.

The various concepts of wear including the adhesive wear concept just described along with several others are the following:

(1) adhesive - interface welds.

(2) corrosive - chemical surface reactions.

(3) abrasive - rough surface and free particle cutting.

It is very likely that, in the wear process for metals used in prosthetic devices, the wear mechanism starts with adhesive wear and then proceeds to abrasive wear and corrosive wear. Both abrasive and corrosive wear can be very important, and, in fact, it is likely that most of the wear debris is formed by abrasion. It is important to remember that the real area of contact of the surface junctions or asperities in contact between loaded surfaces is far less than the apparent area in contact. The real cross sectional area of the junctions is determined by the load and by yield strength in compression that supports the load. As two surfaces come into contact, the high spots or asperities deform plastically until the area is just sufficient to support the load. Motion then causes shear of those small junctions. The real area of contact of the junctions may be no more than one thousandth of the apparent contact area. Shearing of junctions causes very high surface temperatures (ref. 2). Even under much less severe conditions than occur in the prosthetic devices, local flash temperatures several hundred degrees above ambient will readily occur. The presence of these extreme local flash temperatures indicates that corrosive wear must always be considered where reactants are available. The acute concern of orthopedic surgeons for the corrosive behavior of metals in body fluids is based on extensive observations. Corrosion by body fluids can be even more serious when activation by friction processes occurs. As mentioned previously, adhesive wear, corrosive wear, and abrasive wear are the modes considered most pertinent to prosthetic devices.

Figure 6 shows a McKee-Farrar hip prosthesis that was removed from a patient after less than 1 year of service. The upper portion of the figure shows the prosthesis to have a highly polished appearance. The lower portion of this figure shows photomicrographs of wear areas on the ball surface. The condition on the right is indicative of surface welding or adhesion and the subsequent shear which pulls out particles. The surface shows voids from which sheared materials have been removed. On the left is an abrasive wear pattern that was likely developed by cutting action of wear particles generated by prior adhesive wear. Also, rough or high spots on the original surface or rough spots created by transfer of adhering particles can generate abrasive action such as that illustrated on this photomicrograph.

It is important to restrict the action of abrasive particles. They not only can accelerate wear but can destroy clearances between closely mated surfaces. Surface interruption such as crossed grooves can arrest the action of such particles (by limiting their motion) and reductions in wear of more than 90 percent have been observed in reciprocating slider experiments of such interrupted surfaces. This technique can provide pockets for entraped debris.

SUMMARY OF RESULTS

Modern surface measuring techniques were utilized to characterize the geometry and wear processes of metal hip prostheses after removal from patients. The results are as follows:

1. Nonconformity due to out of roundness of prosthetic balls and sockets are sufficient to cause nonuniform loading.

2. Wear associated with prosthetic alloys is considered to be initiated by surface adhesion; subsequently, the wear can progress to abrasive and corrosive wear. Abrasion is the principal source of wear debris.

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National Aeronautics and Space Administration
Cleveland, Ohio, September 30, 1970,
129-03.

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TABLE I. - OUT OF ROUNDNESS MEASUREMENTS OF TWO USED MCKEE-FARRAR HIP PROSTHESES

Item	Serial number	Latitude											
		-15°		Equator		30°		45°		60°		Average	
		mil	mm	mil	mm	mil	mm	mil	mm	mil	mm	mil	mm
Ball	LL 5422	0.28	7.11×10^{-3}	0.28	7.11×10^{-3}	0.35	8.89×10^{-3}	0.10	2.54×10^{-3}	0.10	2.54×10^{-3}	0.18	4.58×10^{-3}
Socket	LL 5422	----	---------	.43	10.9	.30	7.62	.05	1.27	2.01	51.05	.71	18.03
Ball	PP 7353	.35	8.89	.30	12.70	.25	6.35	.30	7.62	.35	8.89	.34	8.64
Socket	PP 7353	----	---------	.28	7.11	.45	11.43	.85	21.6	1.05	26.32	.50	12.70

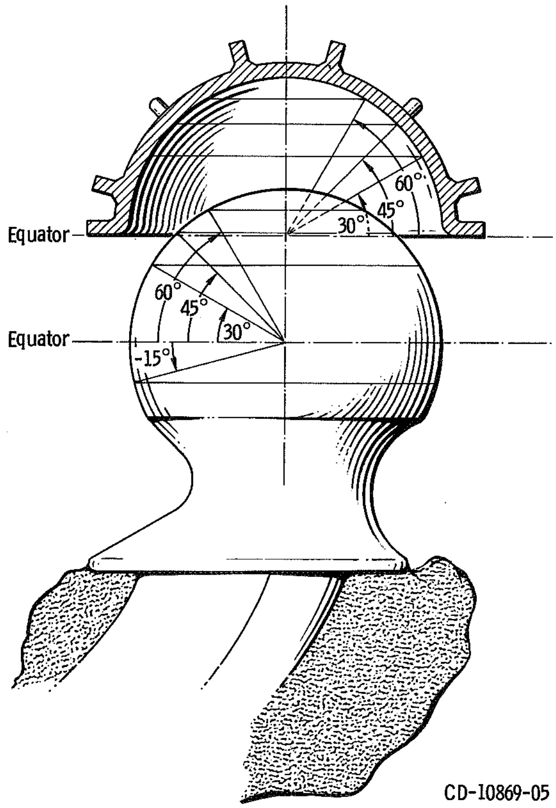


Figure 1. - Location of latitude angle roundness measurements on prosthetic hip joint ball and socket.

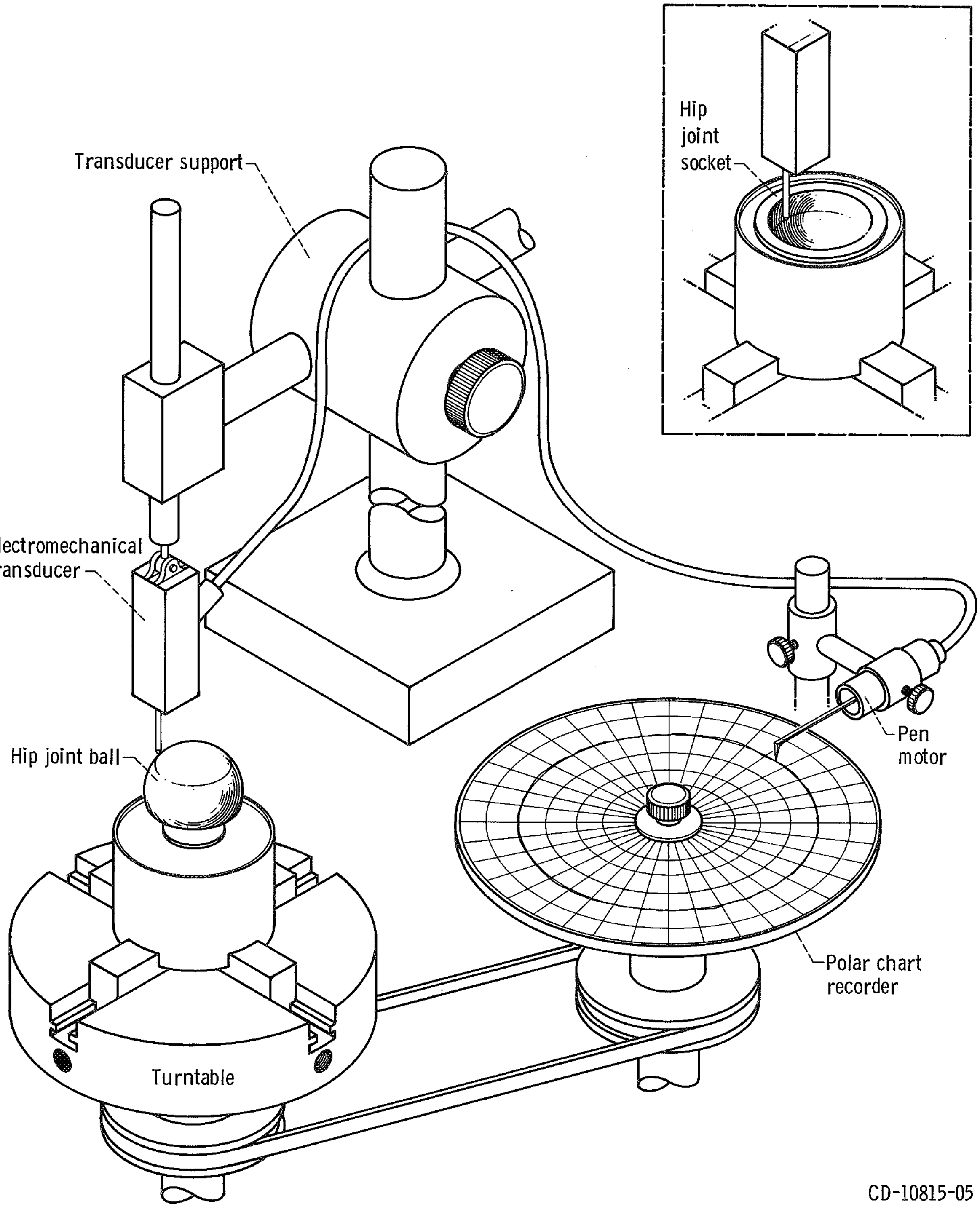


Figure 2. - Roundness gage.

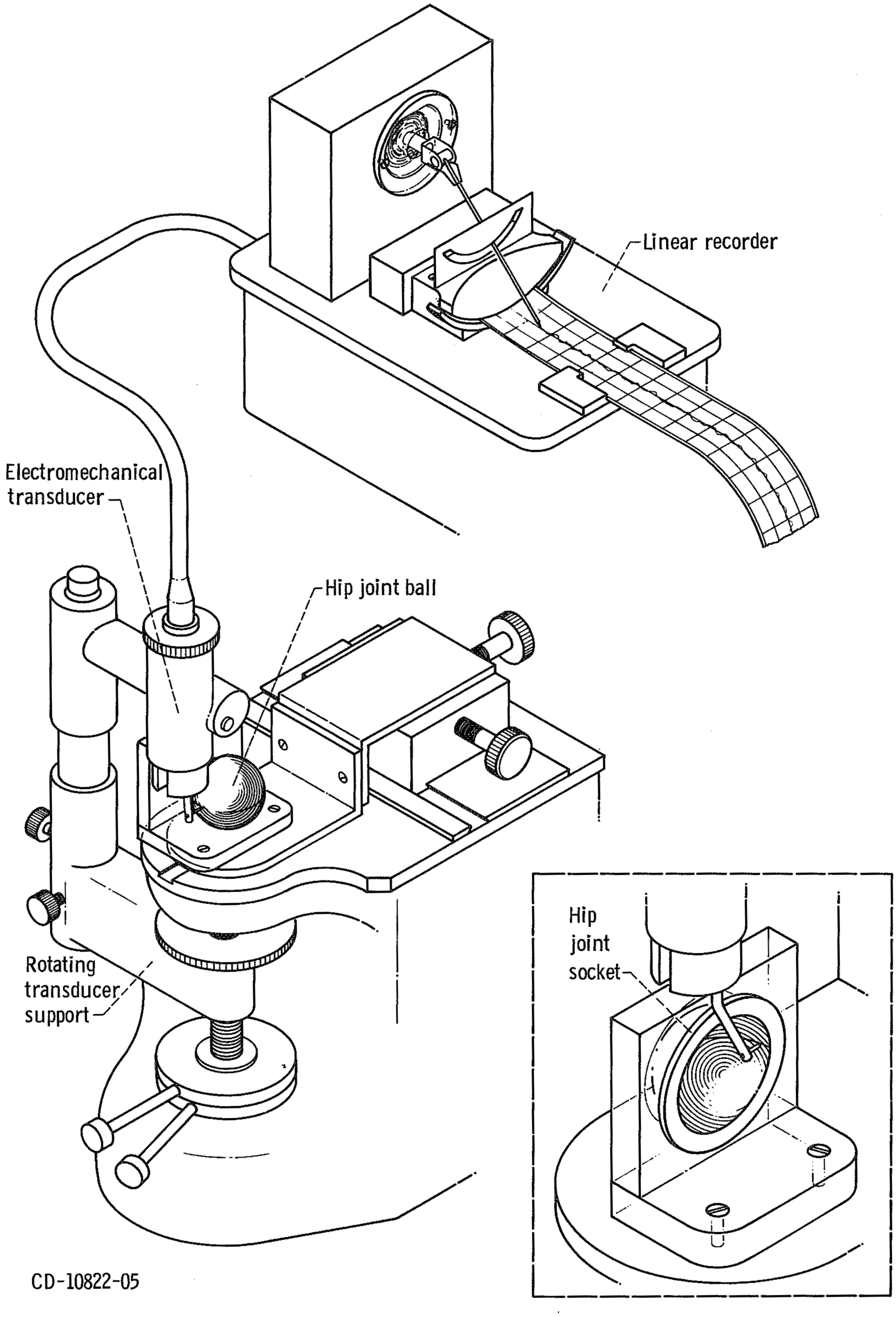
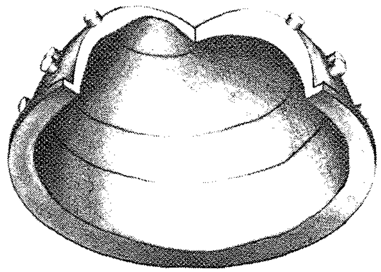
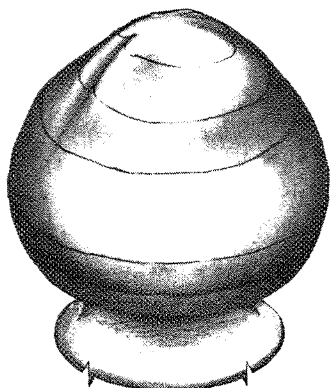


Figure 3. - Surface texture gage.



Hip joint socket



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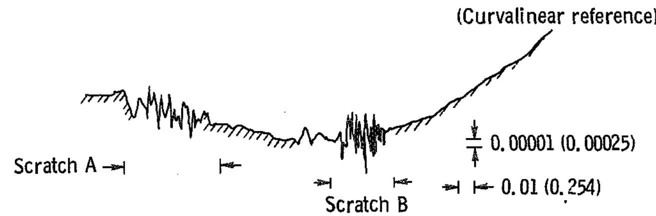
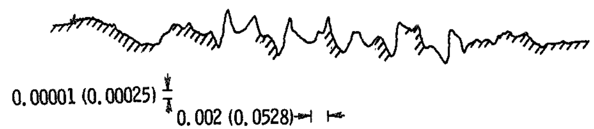
Hip joint ball

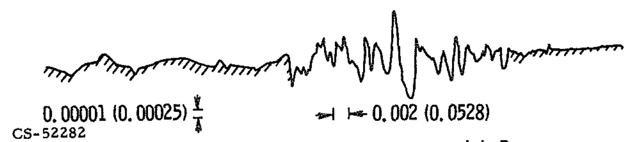
Figure 4. - Isometric sketch from polar chart roundness data of a used prosthetic hip joint ball and socket (S/N LL5422). Geometric error from a true sphere magnified 10 000 times.



(a) Surface texture across two scratches on ball of used hip prosthesis.

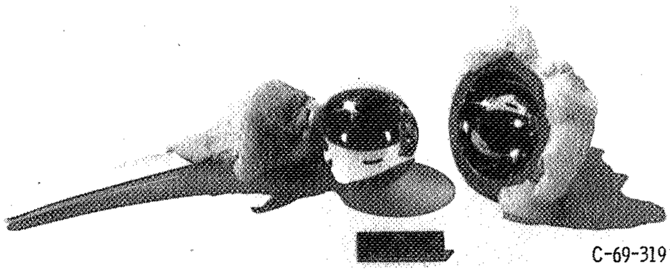


(b) Surface texture of scratch A.

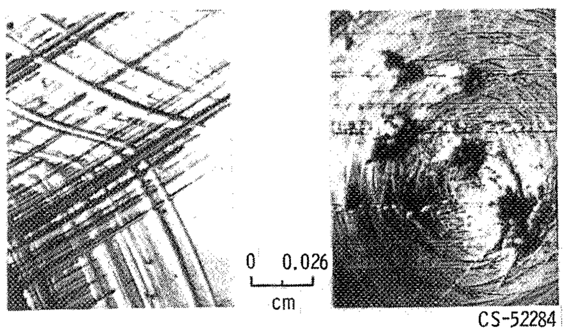


(c) Surface texture across scratch B.

Figure 5. - Surface profile traces of wear scratches from a used metal hip joint ball. All dimensions are in inches (mm).



McKee-Farrar Vitallium hip prosthesis



Wear scratches on ball

Wear area in socket

Figure 6. - Photograph and photomicrographs of a used McKee-Farrar Vitallium hip prosthesis.

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